High-Performance Computing (HPC) Enhancements to Military Research

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OVERVIEW

Application of HPC resources to the survivability of structures under the effects of explosive attacks

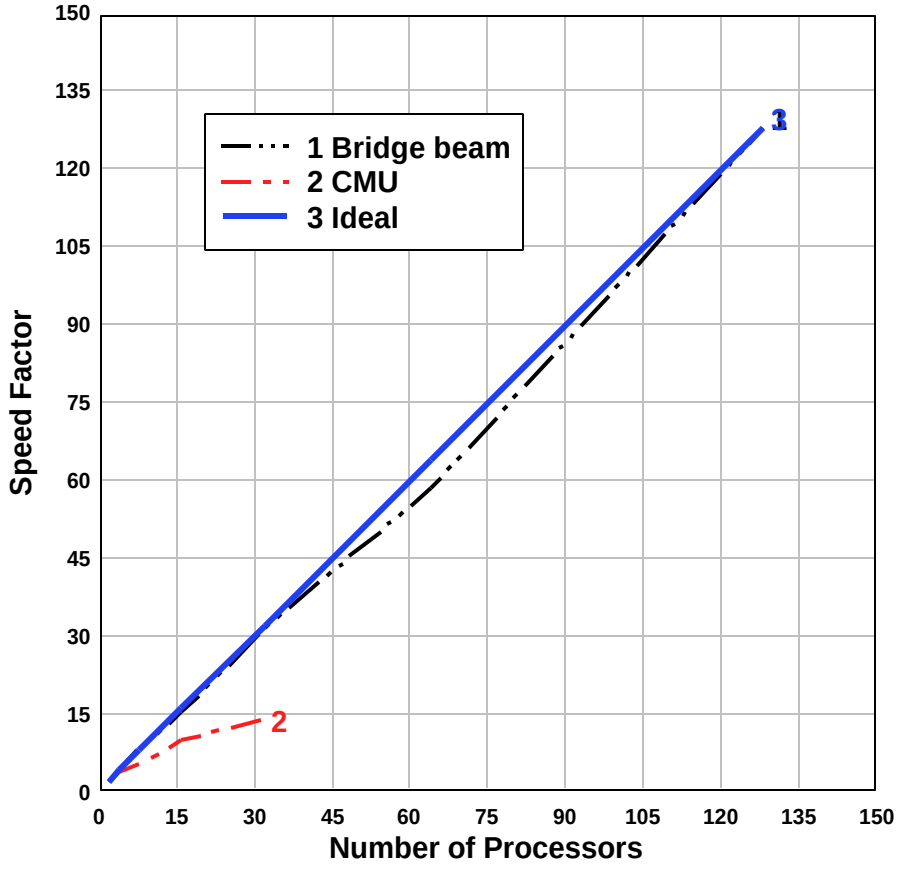
- **Offensive and Defensive attacks**
- **Used for Predictions, Validation, Design, and Model Development**
- **Examples Discussed in this Paper**
  - **CMU walls**
  - **Window Retrofits**
  - **Bridge Beams**

NUMERICAL CODE/ HPC SYSTEM

- CSM Finite Element code ParaDyn (LLNL) used for all simulations (parallel version of DYNA3D)
- Dynapart used to partition meshes onto multiple processors
- Analyses performed at ERDC MSRC on the Origin 2000 and 3000 systems
- Minimum Processors: 2
- Maximum Processors: 64

SCALABILITY

- Bridge Beam exhibited excellent scalability
- CMU did not scale as well
  - due to interface problems
  - only up to 32 processors due to limited problem size



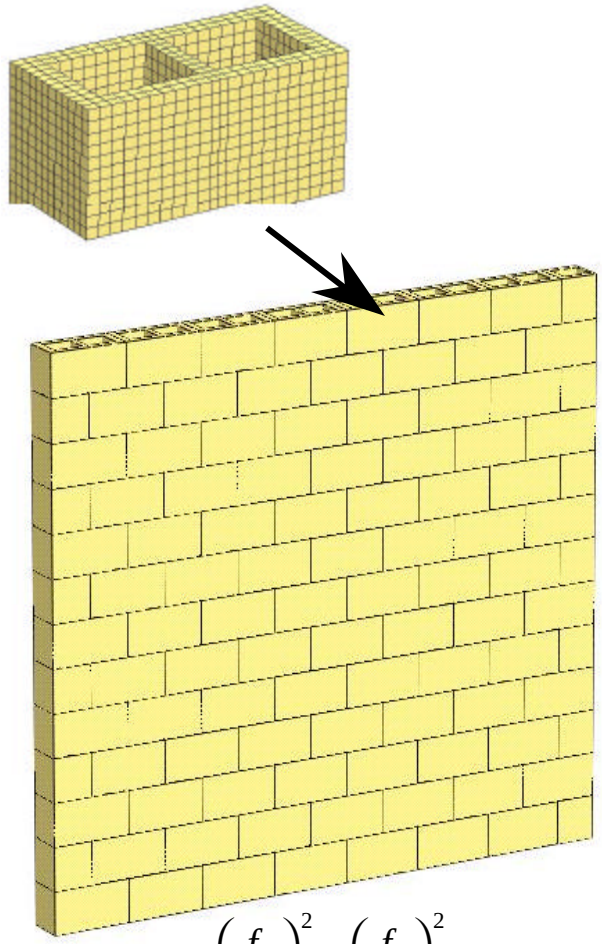
LOAD BALANCE

Number of Processors	Load Balance Error, percent	
	Bridge Problem	CMU Problem
2	0.006	0.41
4	0.043	0.22
8	0.0069	1.94
16	0.143	4.76
32	0.080	1.26
64	8.44	
128	1.24	

Load Balance Error = Maximum processor time - minimum processor time divide by minimum processor time * 100

CMU MODELING

- Each CMU Block discretized with solid continuum elements
- Sliding Interfaces (Contact Surfaces) defined between each block
- Failure Criteria (normal and shear directions) set for each sliding interface

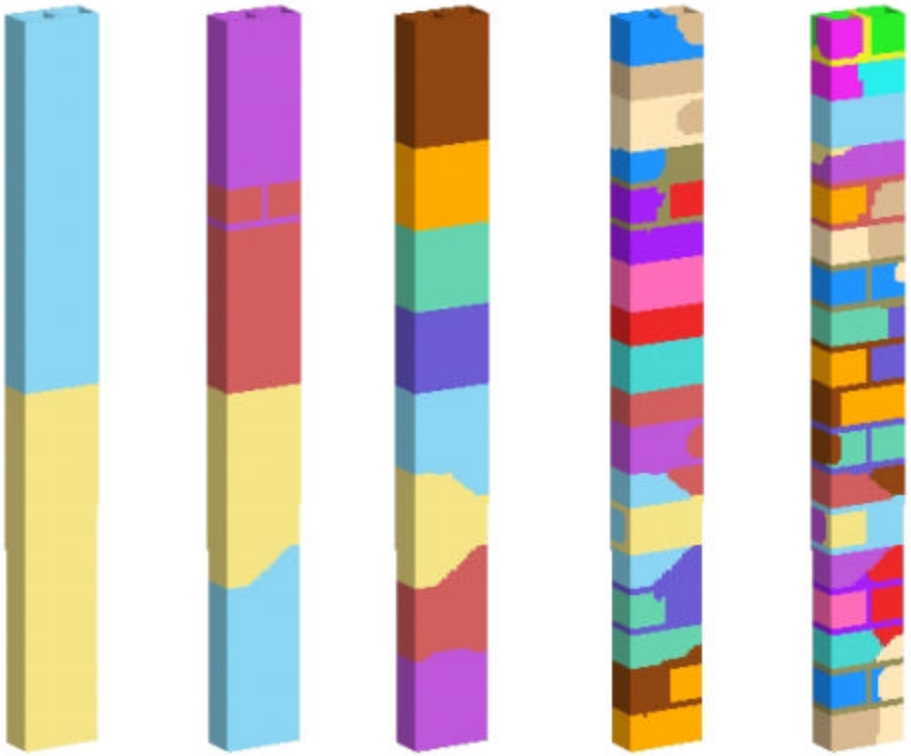


$$\left(\frac{f_n}{F_n}\right)^2+\left(\frac{f_s}{F_s}\right)^2=1$$

Mortar Slide Surface

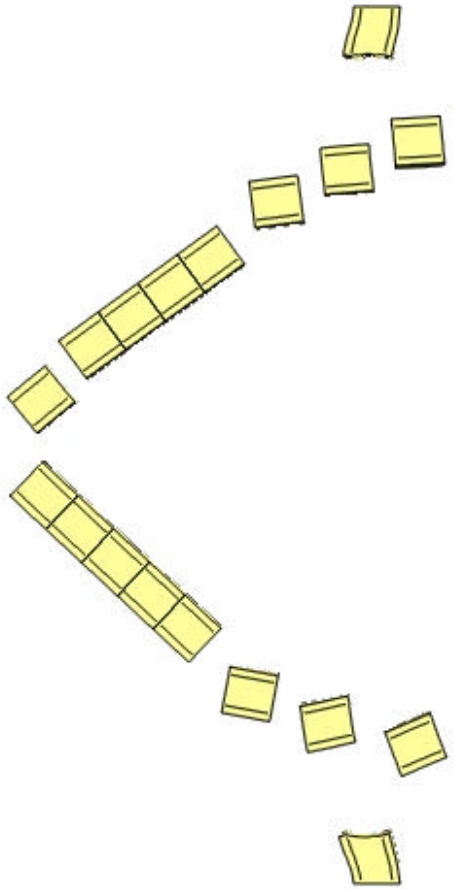
CMU WALL RESPONSE

- Sliding interfaces placed entirely on single processor (required)
- 32-processor run partitioned very poorly
- One block wide wall - one-way response
- Used to design a set of TSWG experiments (> 40 subscale tests)
- Determined charge size and standoff to produce specific wall response and fragment velocity



CMU RESULTS

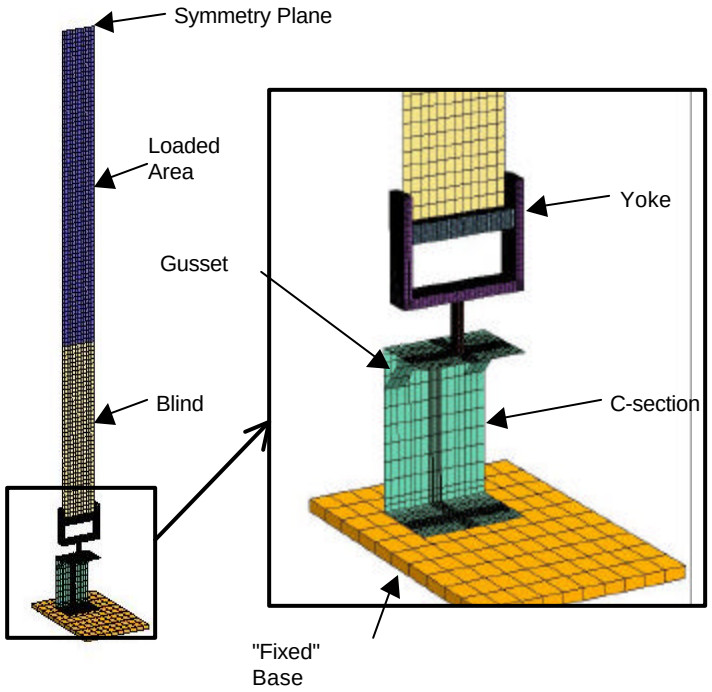
a) Experiment



b) Analysis, t= 100 msec

WINDOW RETROFIT DESIGN

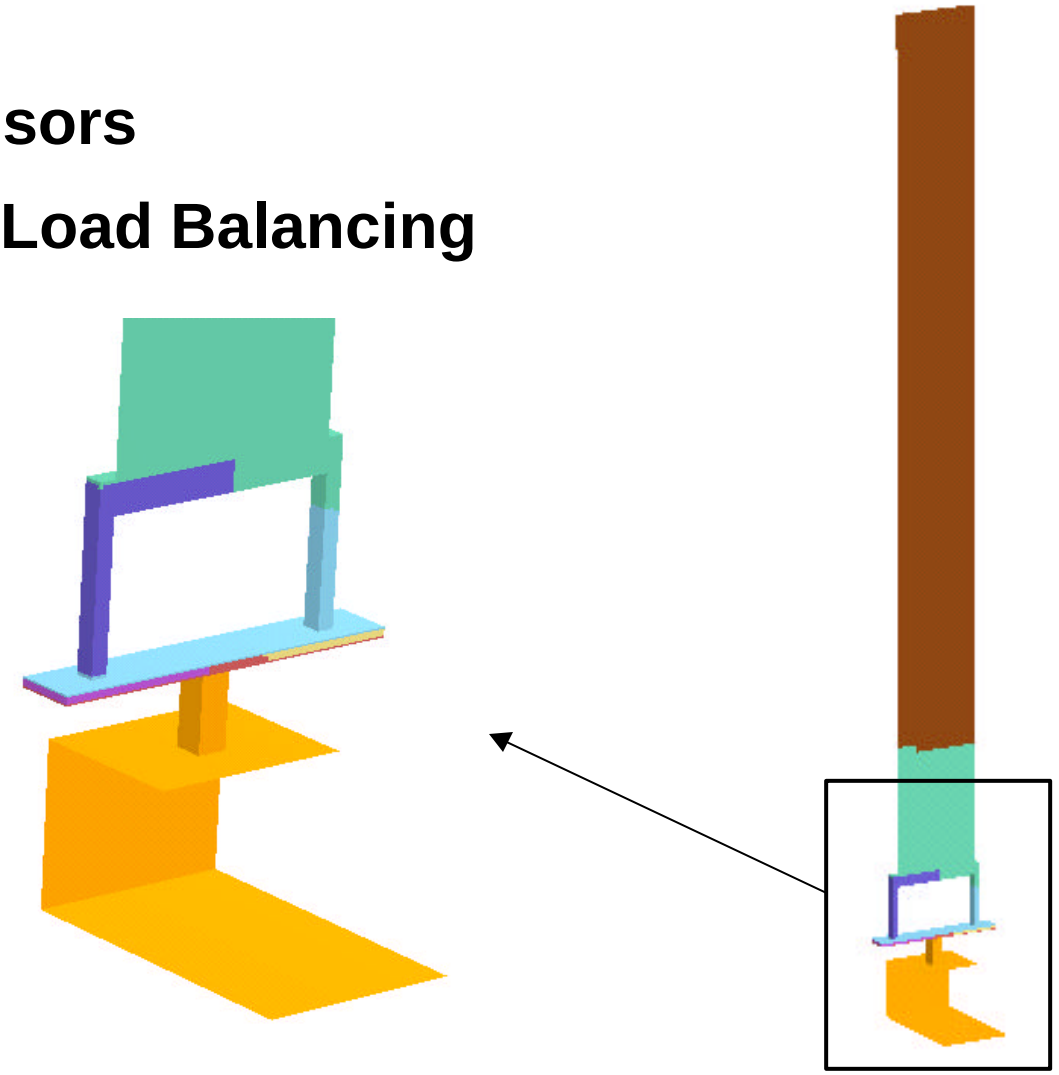
- Protecting people from window debris
- Determining structural integrity of the system
- Analyzed ~40 configurations via finite element model
- Typical model approximately 25,000 elements



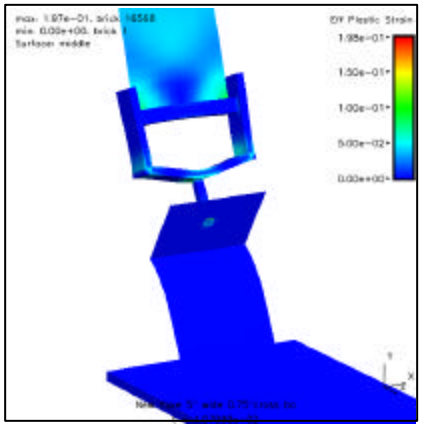
- 4 to 8 Processors per run
- Could not Partition on to 16 Processors
- Several Partitions left without Elements

PARTITIONED RETROFIT MODEL

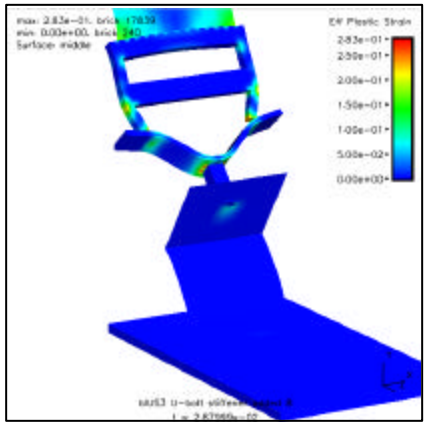
- 16 Processors
- Excellent Load Balancing



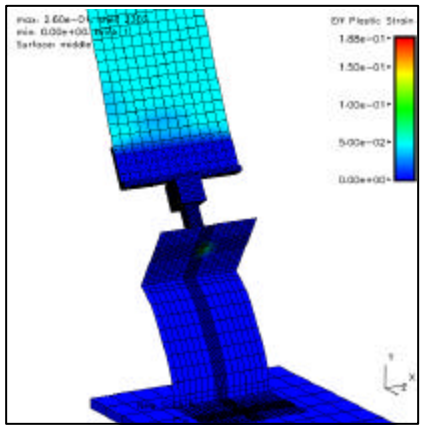
VARIATIONS OF DESIGN TYPES



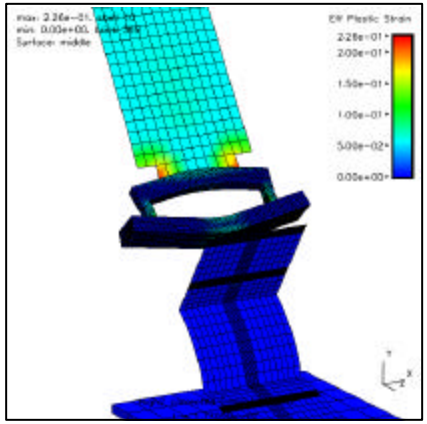
"Yoke" design



Bar and plate design



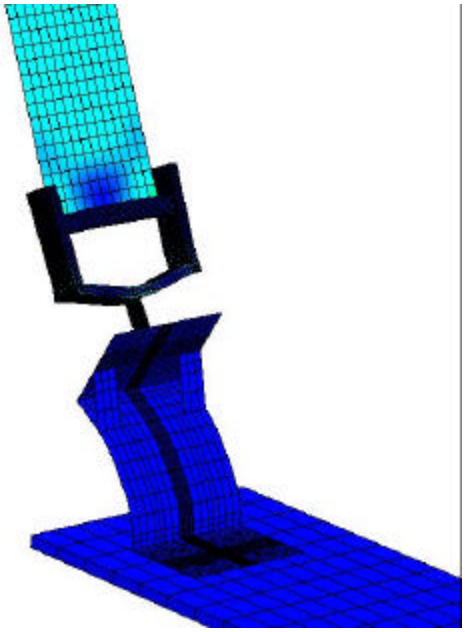
Solid design



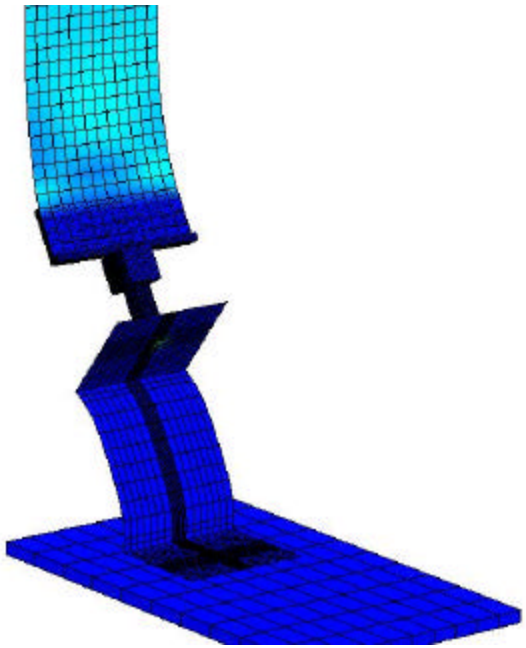
Bar and plate design

WINDOW RETROFIT RESULTS

- **Determined two final designs**
- **Both designs survived the experiment**



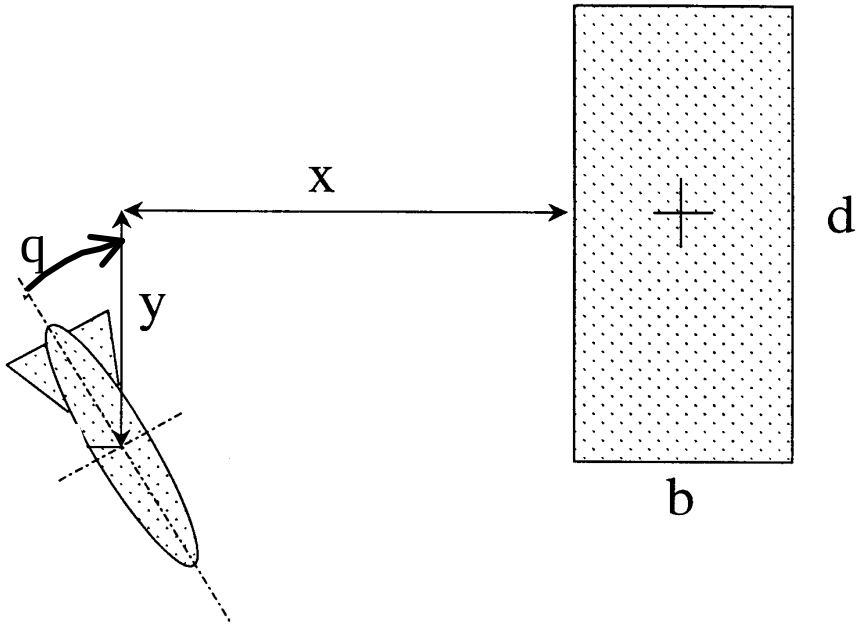
Yoke connection



Solid connection

BRIDGE BEAM RESPONSE

- Wanted to Develop Engineering Level Model
- Seven Weapons
- Bomb Placed at Various Standoffs
- Vertical, 10°, 22.5°, 30°, ar 45° (angled nose-toward and nose-away)
- Concrete Target made Large Enough to Determine Total Extent of Damage
- Damage Superimposed on Actual Beam Size

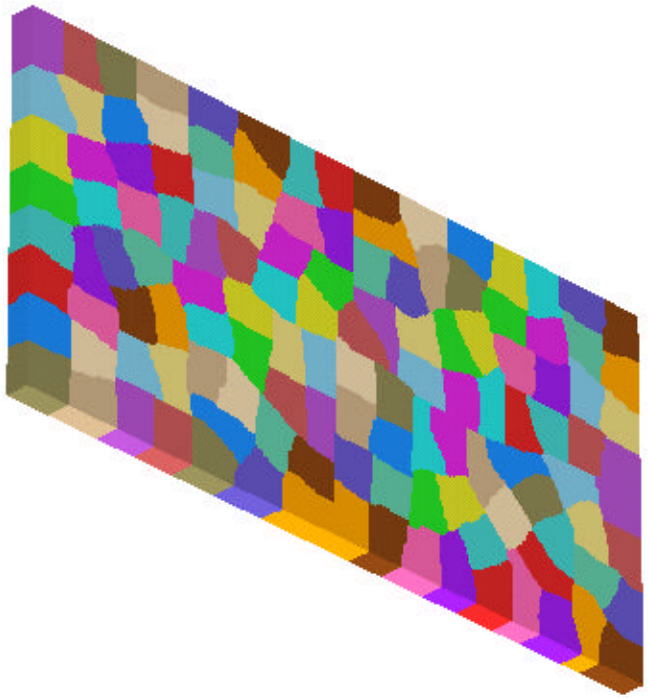


METHODOLOGY FOR MODEL DEVELOPMENT

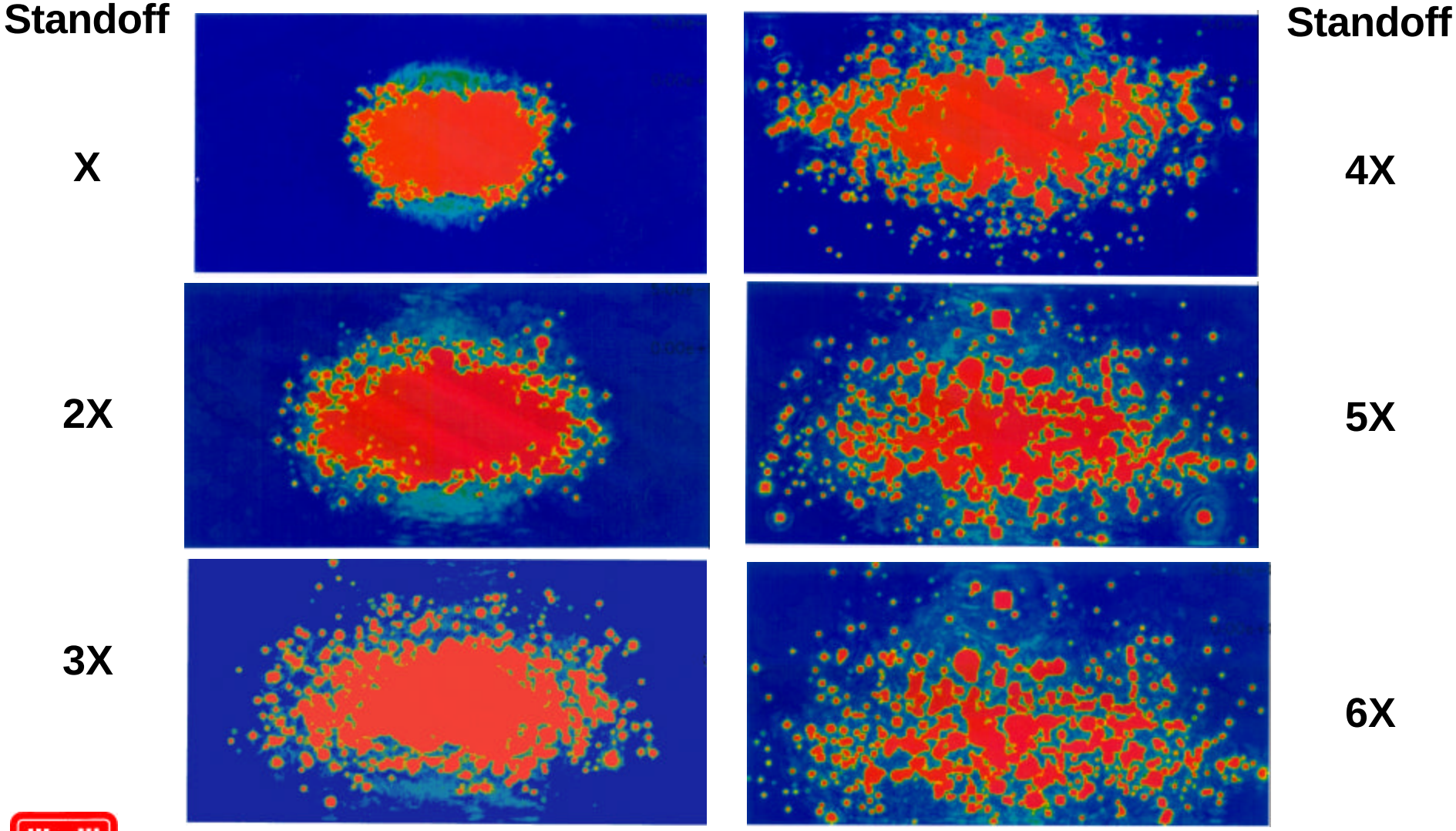
- **Paradyn validated against limited experimental data**
- **Paradyn used to generate extensive database of results**
- **Simplified Method developed from results of extensive database of FE runs**

FINITE ELEMENT MODEL

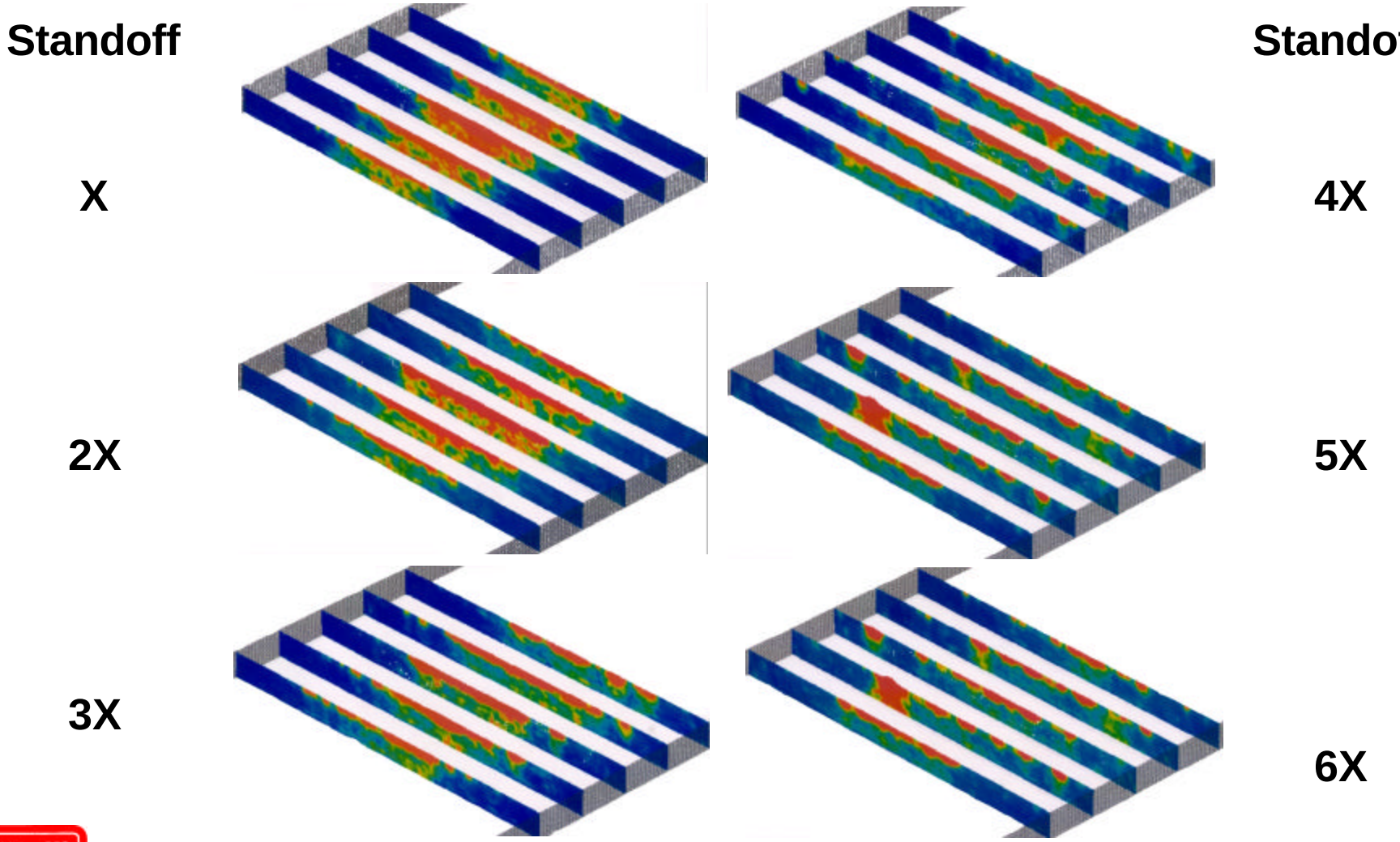
- Applied Pressure Boundary Conditions (representing fragments)
- 1,843,200 solid continuum elements
- 1,970,657 nodes
- No Other Boundary Conditions
- Concerned with ~2.0 msec
- 128 Processors



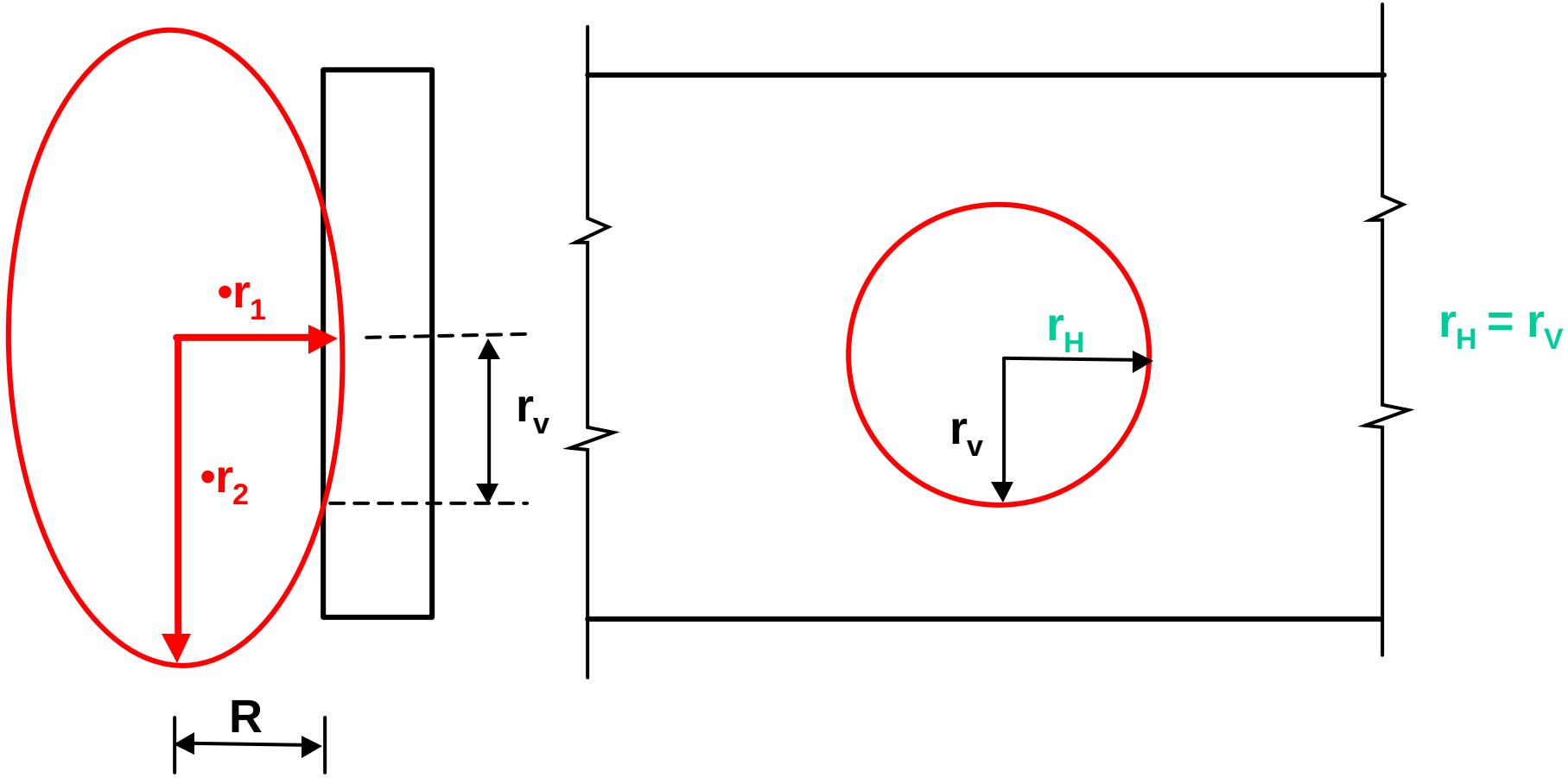
TYPICAL FRONT FACE DAMAGE



Through the Thickness Damage



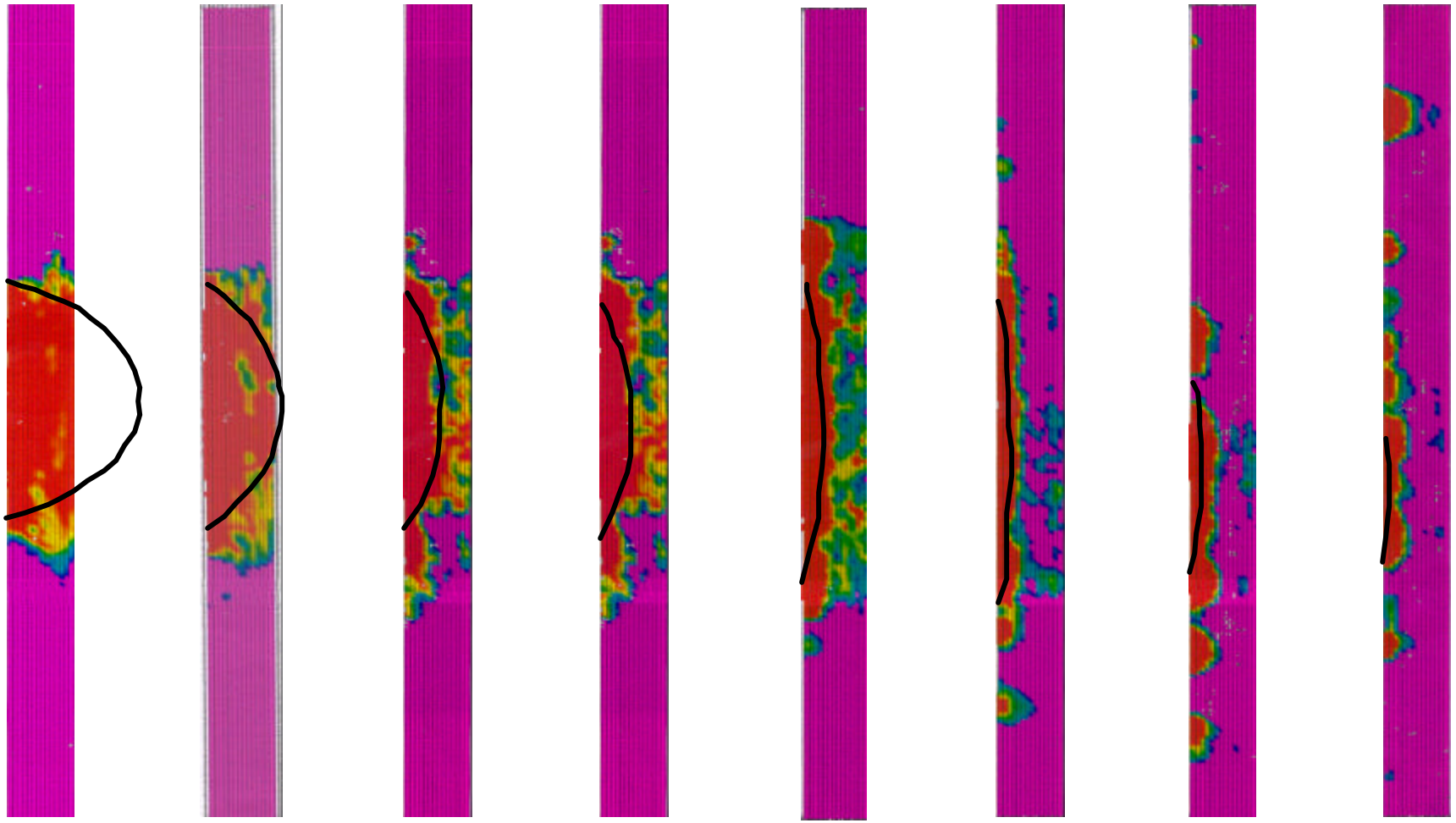
DAMAGE ELLIPSOID



Vertical Plane Through Weapon Normal to Beam

Front Face of Beam Center of Circle Opposite Weapon c.g.

SIDE-ON RESULTS VS ENGINEERING MODEL



0.5 X 0.75 X X 1.5 X 2 X 3X 4X 5X

CONCLUSIONS

- HPC simulations provided invaluable assistance in the prediction, design, and model development for our needs
- Simulations enabled:
  - successful design and execution of the CMU experiments
  - successful retrofit experiment (retrofits survived anticipated load environment)
  - developed engineering model that has been implemented into suite of bridge attack software

FUTURE EFFORTS

Numerically Intensive Problems/Codes:

- **Blast in Urban Terrain**
- **Close-in/Contact Detonations**
- **Arbitrary Lagrangian Eulerian (ALE) calculations**
- **Coupled Codes (CSM to CFD currently)**